Improvement of Energy Efficiency of Coal-fired Steam Boilers by Optimizing Working Parameters of Regenerative Air Preheaters

Sandira ELJŠAN[*1], Nikola STOŠIĆ[2], Ahmed KOVAČEVIĆ[2,] Indira BULJUBAŠIĆ[1]

[1]University of Tuzla, Faculty of Mechanical Engineering, Univerzitetska 4, 75000 Tuzla, Bosnia and Herzegovina
[2]City University London, School of Engineering and Mathematical Sciences , Northampton Square, EC1V 0HB, UK

[*1]sandira.eljsan@untz.ba; [2] n.stosic@city.ac.uk; [3]a.kovacevic@city.ac.uk, [*4]indira.buljubasic@untz.ba

Abstract

The first installation of a Ljungström air preheater on a commercial boiler reduced fuel consumption by as much as 25%, and in modern utility boilers the Ljungström air preheater contributes up to 20% of the overall boiler efficiency while representing only 2% of the total investment. Therefore, in this paper an analysis is shown on how operation parameters of an regenerative air preheater can be optimized in order to increase its efficiency and consequently the overall efficiency of a steam boiler.

Keywords

Energy Efficiency of Steam Boiler; Air Preheater; Numerical Simulation of Processes in Air Preheater; Optimization of Operation Parameters

Introduction

Air preheater is a heat exchanger in which air temperature is raised by transferring heat from other fluid such as flue gas. Since air preheater can be successfully employed to reclaim heat from flue gas at lower temperature levels than is possible with economizer, the heat rejected to chimney can be reduced to a great extent thus increasing the efficiency of the boiler. For every 20^{0}C drop in flue gas exit temperature, the boiler efficiency increases by about 1%. In addition to increase in boiler efficiency the other advantages of using preheaters are: stability of combustion is improved by use of hot air, intensified and improved combustion, burning poor quality fuel efficiently, high heat transfer rate in the furnace and hence lesser heat transfer area requirement, less unburnt fuel particle in flue gas thus complete combustion is achieved, intensified combustion permits, faster load variation. Lower grades of coals can be burnt efficiently with hot air.

The simple calculation of heat transfers between the hot combustion products and solid material on the one side and the cold air and solid body on another side, can be used to estimate the pre-heater performance sufficiently well. However, a more precise and accurate calculation must be used to determine precise influence of the input design and operation parameters upon the process. For this purpose more comprehensive models are required.

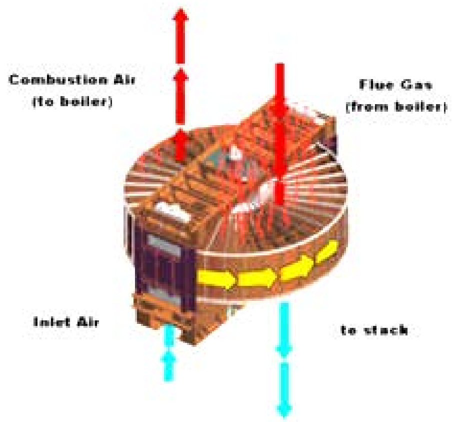

FIG. 1 FLUID FLOW IN ROTARY AIR PREHEATER

Numerical Modelling of Fluid Flow and Heat Transfer in Rotary Air Preheater

The 1D and 3D numerical models of heat transfers between the hot combustion products and solid material on the one side, and the cold air and solid body on another side are used here to estimate the pre-heater performance. More details are given in references, where the methods used and the applied numerical and experimental techniques were described and a full set of calculation and experimental results and their comparison were presented. 1D two-fluid model consists of three energy balance equations, two for the gas phases and the other one for a solid body. 3D two fluid and one solid body model is described by a set of differential

transport equations of continuity, momentum, energy. The space conservation equation, as well as the turbulence transport equations and equation of state complete the model. This mathematical scheme is accompanied by the boundary conditions for both, the solid and fluid parts.

The result are obtained in the form of instantaneous temperatures of air and flue gases, instantaneous temperatures of solid and mass flow of the air and flue gases for each point along the axial coordinate.

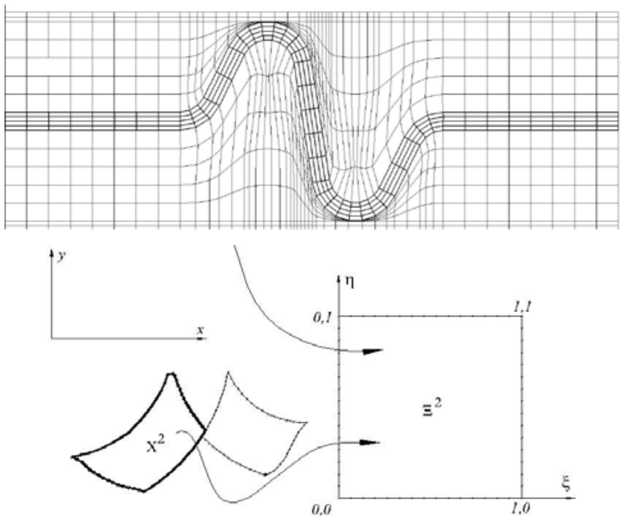

FIG. 2 NUMERICAL GRID WITH ADAPTED BUNDARIES AND MAPPING OF PHYSICAL DOMAIN FROM X^2 TO CALCULATION DOMAIN Ξ^2

Spatial domain of the pre-heater is replaced by numerical grid that contains discrete volumes. A boundary fitted and confirmed numerical meshes are generated for each part of both, the fluid and solid parts. The grid generation method is implemented in a pre-processor program developed by authors in order to produce a numerical mesh suitable for analysis of a rotary regenerator and to incorporate it automatically into the existing finite volume software.

Influence of Air Preheater Operating Parameters on Boiler Efficiency

In this paper a calculation is made of the heat transfer process within the rotary air preheater for variable heat load of 200, 170 and 140 MW at one speed of rotation, of 1.76 rpm, Table 1 and for different rotational speed for one fixed unit power of 200 MW, Table 2. The rotary preheater serving boiler 5 of Unit IV in Tuzla Power Plant is used as object of investigation. A numerical solution was obtained for a variety of working conditions for some of which the experimental results exist.

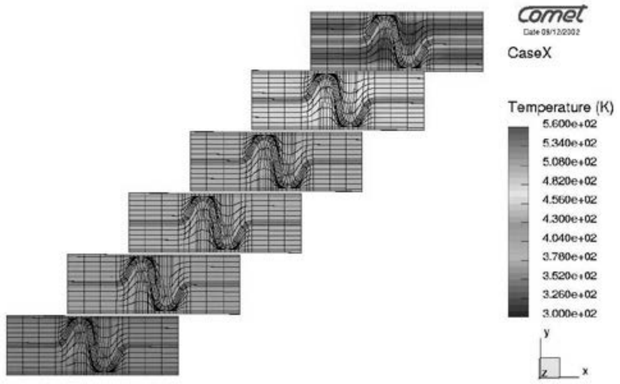

FIG. 3 TIME STEP 1, ROTOR ANGLE 3.36

TABLE 1: CALCULATION RESULTS FOR LJUNGSTRÖM AIPREHEATER, UNIT IV, TE TUZLA, 200 MW AT 1.76 RPM FOR THREE DIFFERENT PLANT LOADS

Plant load (MW)	Temperature of flue gas (°C)	Air temperature (°C)
200	161.8	260,1
170	159,4	257,2
140	158,8	254,1

The analysis of the influence of rotation speed upon the preheater process may start with two extreme cases. In the case of extremely low speed of rotation, practically there is no rotor movement and the heat transfer will be minimal if not zero. The both flows will maintain the same inlet temperature along the complete height of the regenerator and it will be the same at the preheater outlet. (Fig.3).

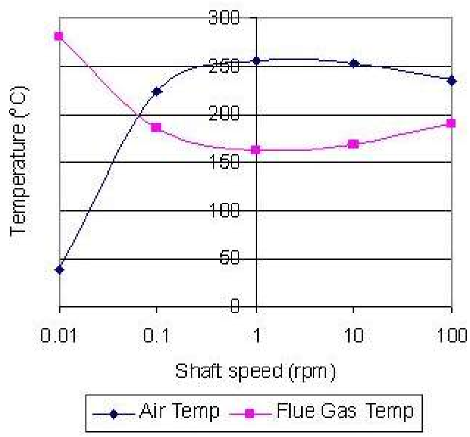

FIG 3 OUTLET TEMPERATURES OF AIR AND FLUE GAS FOR VARIABLE SPEED OF ROTATION

On contrary , if the rotation speed is extremly high, time of the surface exposure to the each fluid flow will be too short to change significantly the metal filling temperature and it will stabilise at certain level, similar to the exit temperature of a parallel flow heat exchanger. Then, the outlet temperature of both fluids will tend to the filling temperature.

TABLE 2 CALCULATION RESULTS FOR LJUNGSTRÖM AIR PREHEATER, UNIT IV, TE TUZLA, 200 MW FOR DIFFERENT ROTATION SPEEDS

Rotation speed (rpm)	**Temperature flue gas (°C)**	**Air temperature (°C)**
1.0	164.5	254.3
1.76	161.8	260.1
2.2	158.4	265.3
2.6	155.6	267.5
3.0	153.4	269.4
5.0	159.5	264,3
10.0	170	254
100	190	235

Efficiency of regenerative air preheater ε was calculated for different rotation speeds and results are shown in Table 3. These results show that by increasing the rotation of speed up to the optimum number of 3rpm, the efficiency of air preheater also increases as well as overall efficiency of a steam boiler. After this speed, the efficiency of air preheater decreases again, which consequently causes a decrease in boiler efficiency.

TABLE 3 EFFICIENY OF REGENERATIVE AIR REHEATER FOR DIFFERENT ROTATION SPPED AND 200 MW LOAD

Efficiency	Rotational speed of air preheater (rpm)						
	1.0	1.76	2.2	2.6	3.0	5.0	10.0
ε	0.89	0.91	0.934	0.944	0.952	0.931	0.88
η_k	0,861	0.863	0.864	0.866	0.867	0.863	0.856

Conclusions

On the basis of the analysis described in this paper, it is concluded that efficency of the rotary regenerative exchangers depends on various operating parameters, of which only rotation speed is presented in this paper. The most efficient heat transfer for the preheater in question was achieved at 3.00 rpm which is almost twice than the current speed. Unfortunately, the increase of rotation speed enhances mixing of hot and cold fluids which would require additional studies before it is implemented. In order to truly optimize work of air preheater, all parameters (load, solid filling geometry, rotation speed) should be taken into account at the same time. However, this requires more complex modelling and calculations which are not presented in this paper.

REFERENCES

Alagic, S: A Numerical Analysis of Heat Transfer and Fluid flow in Rotary Regenerative Air Pre-Heaters, PhD thesis, Tuzla, 2003.

Alagic, S, Stosic N., Kovacevic, A and Buljubasic, I: A Numerical Analysis of Heat Transfer and Fluid Flow in Rotary Regenerative Air Pre-Heaters, Strojniški Vestnik, Vol 51, 7-8, 411-417, 2005.

Alagic, S, Stosic, N., and Kovacevic, A. : Influence of rotational speed upon heat transfer in a rotary regenerative heat exchanger, TMT 2008, Istanbul, Turkey, 2008.

Baclic, B.S, and Dragutinovic, G.D: Operation of Counterflow Regenerators; Computational Mechanics Publications Southampton, UK and Boston, USA, 1998.

Demirdzic, I, and Muzaferija, S: Numerical Method for Coupled Fluid Flow, Heat Transfer and Stress Analysis Using Unstructured Moving Mesh with Cells of Arbitrary Topology, Comp. Methods Appl. Mech Eng, Vol.125 235-255, 1995.

Ferziger, J H, and Perić, M: Computational Methods for Fluid Dynamics, Springer, Berlin, 1996.

Kovacevic, A, Stosic, N, and Smith, I.K., "Screw Compressor Three Dimensional Computational Fluid Dynamics and Fluid Solid Interaction", Springer, 2006, ISBN 3-540-36302-5.

Zafeiriou, E, and Wurz, D. : Numerical Simulation of Heat Transfer Processes in Rotating Regenerators, VGB Kraftwerkstechnik 76, Number 6, 1996.